$n\lambda c$ equally constant, and so, if we take $n \propto T^{1.5}$ (see (19)), we have $\lambda \propto T^{-2}$, approximately.

24. In the attempt, not hopeless, which I have been making of late to explain the various "transverse" effects in accordance with the propositions of my *Summary*, I have been led to the conclusion that the diameter of the outer electron shell of an atom may be as small as one-half the means centre to centre distance of neighboring atoms. This conception makes it comparatively easy to accept the proposition that λ may be, as already indicated in (21), fifty[8] times as great as this centre to centre distance.

If λ really extends through many one-atom-thick layers of the metal, a slight decrease in the probability of an electron's passing through any single layer would be enough to account for the rapid decrease in λ with use of temperature, as found in (23).

[1] "A Possible Function of the Ions in the Electric Conduction of Metals," PROC. NAT. ACAD. SCI., Vol. 3, March 1917.

[2] *Journal de Physique,* series 4, vol. 4, pp. 690–692.

[3] See pp. 86–88 of his *Molecular Constitution of Matter.*

[4] Borelius makes a like assumption regarding the kinetic energy of what he calls free electrons. See *Ann. Phys. Chem.*, vol. 57, p. 233.

[5] In the paper referred to in footnote (1), I held quite the opposite opinion, making the effect of the field at this juncture the basis of my explanation of Ohm's law.

[6] If this conception is sound, it would not be surprising to find very great pressure unfavorable to the state of superconductivity.

[7] For a *Summary* see PROC. NAT. ACAD. SCI., **7,** No. 3, March 1921.

[8] Bridgman has of late taken λ to be "many" times the atomic diameter.

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*STATIC DEFLECTION, LOGARITHMIC DECREMENT AND FIRST SEMI-PERIOD OF THE VACUUM GRAVITATION NEEDLE**

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1. *Apparatus.*—The object of the present experiments is a completion of the work of an earlier paper,[1] by carrying the exhaustion of the case as far as practicable.

In spite of the care taken to seal all parts of the extended apparatus, there remained a constant leak of .0035 mm. of mercury per hour, the seat of which I was unable to detect; but as experiments with gradually decreasing vacua were primarily contemplated, this leak was here no serious

disadvantage, except that the highest exhaustions were not available. It is of course possible to keep the pump running and the stopcock open. When this is done, however, the needle (quite apart from tremor) is always in motion, so that gravitation measurements are out of the question.

2. *Data. Logarithmic Decrement,* λ.—In the work of last year the logarithmic decrement as obtained from observations largely made at night, seemed to remain fairly constant until the highest exhaustions were approached. This result needed the further qualification undertaken in the present paper. To compute $\lambda \log e$, the two arcs obtained from the first three elongations of the needle $y - y'$, $y' - y''$ were used. In view of the specified small leak in the apparatus, the data for λ could be found with great accuracy in this way in the course of time, while the vacuum slowly degenerated from about .0002 to .271.

These data and the vacua to which they belong (observations being made in the morning (A), afternoon (P), and night (N)), are constructed in relation to the vacua (mm. of mercury) in figure 1. F denotes that the attracting weight M, on the right, is in front, and R to the rear of the case and needle, the opposite conditions holding for the M near the left end of the needle. The first arc of swing was usually between $y = 20$ and $y = 30$ cm., depending on the time of day.

Inspection of figure 1 shows that changes of viscosity due to changes of pressure, are not discernible in results of the present kind. In fact the logarithmic decrement at the highest exhaustions (July 5) happens to be larger than at the lowest exhaustions (July 8, N). The logarithmic decrement is therefore, also, primarily under the influence of the radiant forces. It is largest in the morning, and least at night. It obviously oscillates once per day, though I did not make observations after 11 P.M. If $d\Theta/dt$ be the change of atmospheric temperature per second in the environment of the apparatus, then this coefficient is the controlling factor in the marked variations of $\lambda \log e$.

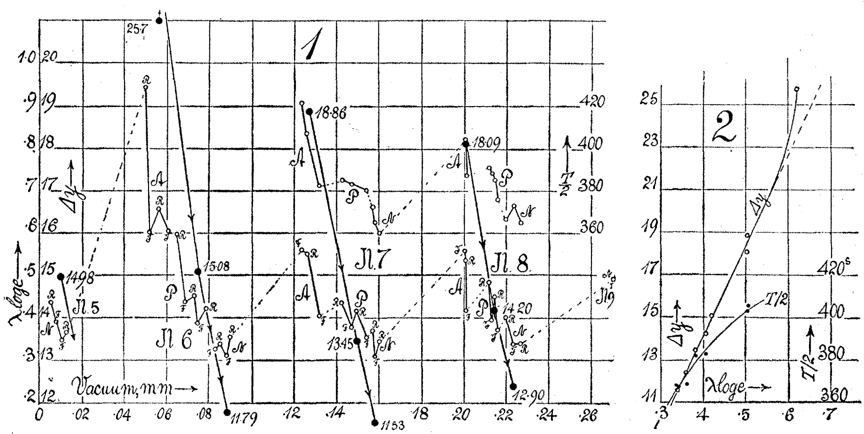
Moreover the values of $\lambda \log e$ are always larger for the rear positions R of M, than for the front positions F, under otherwise like conditions. One or the other, or their mean, must therefore be taken in association with $d\Theta/dt$. This may be due to a lack of symmetry of the position of the needle to the case; but it is more probably due to a lack of symmetry in the environment.

3. *First Semi-Periods.*—The accurate method of finding $T/2$ from two successive passages of the needle through the position of equilibrium is very troublesome; for $T/2$ is long and the position of equilibrium varies. Similarly the variations of $T/2$ are large, and precise values of it are here apparently of little use. Hence the measurement of $T/2$ from elongation to elongation was accepted as adequate. These values, so far as taken,

are constructed in figure 1, on the right, in seconds. The variations may run from 6 to 7 minutes and the $T/2$ values are largest in the morning and least at night. They march about in parallel to the λ values, if either the R or the F position alone is taken. T thus also varies harmonically in the lapse of time with a period of 24 hours referable to $d\Theta/dt$, provided the first semi-period, $T/2$ is taken.

From these results it might be surmised that the true period T can be computed from the log decrement observed at the same time. But it is easily seen that the correction so obtained is of an order entirely too small to account for the existing divergencies. The theory of the damped pendulum is only useful here as an analogy.

4. *Static Displacements*, Δy.—Continuous series of these data were given in the earlier papers and obtained from night observations (7–11 P.M.), when they are liable to be most constant. The black dots in figure 1 are the present values for different parts of the same day. Δy is the



static displacement finally obtained, when the attracting weights M are swung from one side of the needle to the other. As figure 1 shows, Δy is now also markedly harmonic in the lapse of time, or of the reduced exhaustion proportional to time, with a period of one day.

We thus come to the result that λ, $T/2$, Δy are similar time functions; that as a first approximation they are independent of the change of viscosity of rarified air and that their relative variation is such as to admit of their expression in terms of each other. It does not necessarily follow that a correct value computed for one (for instance for λ) would lead to correct values for $T/2$ and Δy; but it is a project well worth testing.

5. *Comparison of* λ, $T/2$, Δy.—It is next necessary, therefore, to more specifically compare all the quantities obtained in the present investigation. This has been done in figure 2, where the abscissas are $\lambda \log e$ and the ordinates $T/2$ and Δy, respectively.

Turning first to the latter, it is astonishing to find that λ and Δy, in spite of the marked amplitude of radiant forces, make up a definite graph. In fact, if we omit the exceptional $\Delta y = 25.7$ (inadmissably large radiant forces), Δy and λ are nearly proportional. If this curve were known, Δy could be computed from λ and vice versa.

The values of $T/2$, as already intimated, were not accurately taken, as I did not anticipate relations like the present. Nevertheless figure 2 adequately shows that these also make out a definite graph.

If for instance $\Delta y = 13.4$ cm.(about the mean value in the preceding paper), $T_1 = 758$ sec. should be its equivalent and $\lambda \log e = .385$ at the same time. If we take the vacuum period as $T_1/\sqrt{1+\lambda^2/4\pi^2}$ it would be $T = 750$ sec. which happens to agree with the value taken in the report in question.

6. *Plenum.*—In contrast with the preceding oscillations under conditions of high exhaustion, the results investigated for the case of the needle vibrating in air under atmospheric pressure, are nearly aperiodic. The data for T, λ, Δy, are all enormously larger. These values of λ result from the continued drift of the position of equilibrium of the needle toward the direction in which it is deflected by the attracting weights M. In this respect the plenum results are quite different from the preceding under exhaustion.

The motion of the needle in a plenum is peculiar. When the weights are exchanged, the needle falls from its high elongation to its low elongation in the time $T/2$. It then turns toward a new high elongation for a time (usually about $T/4$ sec. in length), after which it again moves toward low numbers by slow indefinite creeping, without again turning. Exactly the same phenomenon occurs when the needle rises from a low elongation toward a higher. In other words the needle may be said to oscillate about a position of equilibrium continually advancing in the direction of the deflection.

7. *Comparison with Theoretical Values of Frictional Resistance.*—It is now desirable to endeavor to construe the values obtained for λ and T by the aid of the familiar theory of the damped pendulum. If the needle be regarded as consisting of the two balls at its end, the frictional forces should be $6\,\pi\eta\,r\,v$ and therefore the frictional coefficient b is $6\,\pi\,\eta\,r$. If T_1 is the period of the damped needle and λ its logarithmic decrement $T_1 b = 2\lambda$, and therefore, $\lambda = 3\,\pi\,\eta\,r\,T_1$. Hence, if $r = .23$ cm., $\eta = .00019$, $T_1 = 892\,\lambda \log e$ seconds. In figure 2, however, not only is proportionality of T and λ at long range excluded, but the factor would be twice as large, on the average.

* Advance note, from a Report to the Carnegie Institution of Washington, D. C.

[1] These PROCEEDINGS, **8**, pp. 13, 63, 1922. The present apparatus is essentially the same.